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Vulnerability of Santa Clara Valley Water District Imported Water Facilities and Potential Impacts from Invasive Dreissenid Mussels

Technical Memorandum

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Santa Clara Valley Water District

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Mussel Control Measures at Imported Water Intakes

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Executive Summary

Zebra and quagga mussels (collectively referred to as dreissenid mussels) are non-native, invasive mussels. They represent an environmental and economic nuisance, with the potential to harm ecosystems, affect water system reliability, damage equipment and infrastructure, and they may require significant investment to control. Since the discovery of zebra mussels in neighboring San Justo Reservoir in San Benito County in January of 2008, the Santa Clara Valley Water District (SCVWD, District) has taken several measures to prevent dreissenid mussels from infesting its raw water conveyance system. These measures have included boating inspections on four reservoirs and closure of boating on others except by special permit (e.g., rowing club, ski club); preparation of mussel vulnerability assessments for three pumping plants, local reservoirs, and water treatment plants; implementation of regular mussel monitoring; and development of an invasive mussel response plan.

The development of invasive mussel control measures for imported water intakes is a key portion of the long-term response measures outlined in the invasive mussel response plan. This technical memorandum assesses the vulnerability of raw water distribution components from the San Luis Pacheco intake line to the Pacheco Pumping Plant and the South Bay Aqueduct (SBA) Mission Tunnel to the SBA Terminal Tank for colonization by zebra and quagga mussels, and it serves as the first step in the effort to develop invasive mussel control measures for imported water intakes.

RNT Consulting Inc. examined environmental parameters of the District's imported water to better understand the size of the potential infestation. Assessment of environmental suitability for mussel infestation is essential when assessing the vulnerability of facilities and structures.

The SBA Terminal Tank and the Pacheco Pumping Plant facility were evaluated for vulnerability if mussels become established in imported source waters. Elements of the facilities were identified that would be vulnerable to fouling should the mussels survive in sustainable numbers.

The data available from SCVWD shows calcium levels which would generally be considered adequate to support low or moderate population levels of dreissenid mussels in the South Bay Aqueduct and San Luis Reservoir (based on comparisons to data from eastern North America and Europe). However, SBA and San Luis Reservoir water frequently have relatively high pH. Experience from San Justo Reservoir indicates that marginal calcium concentrations can support greater mussel densities in cases where the pH is high. Therefore, it is possible that the SBA water could support a moderate dreissenid population and San Luis Reservoir could support a moderate-to-high dreissenid population.

Examination of additional environmental parameters has not revealed any which would decrease the possible dreissenid populations described above.

Large diameter piping and tunnels are not at risk of plugging from mussels, but they are at risk of mussel settlement on the walls. Some increased hydraulic roughness is to be expected from mussel attachment, and the increased hydraulic friction will reduce the maximum flow that can be achieved in this largely gravity-based piping system. Provided the system flow capacity is oversized, some increased hydraulic roughness should be tolerable. Once source waters reach the water treatment plants, live mussels or dead shells will be removed. Even if mussel settlement is acceptable from a hydraulic perspective, settled mussels will eventually become a source of dead shell material that will be transported along the piping and deposited in areas of low flow velocities. Therefore, some increased operations costs for cleaning will be necessary.

Similarly, large valves are minimally impacted by mussels. Smaller components such as air release valves, blow off valves, instrument lines, and level gauges are typical components that may have increased maintenance or sometimes impaired performance.

Should SCVWD decide to treat all the source water taken from the San Luis Reservoir, suitable chemical injection locations are available either at the intake tunnel or the intake surge tower. A continuous treatment process at San Luis Reservoir would keep mussels out of the protected equipment and infrastructure. Alternatively, if some settlement is tolerable in the SCVWD system, it is possible that a once per year treatment could be practical that would allow some mussel growth within the system which is subsequently removed once per year.

Large tanks such as the SBA Terminal Tank and the Pacheco regulating tank are locations where low velocity water flow will allow transported mussel shells to settle out. Some increased cleaning of the tanks may become necessary.

At Pacheco Pumping Plant, the pump unit cooling water components will need to be protected. Filters, UV, or chemical injection would all be suitable protection options at the preference of the plant engineers.

The Pacheco fire protection system will need some improvements, such as shell strainers to assure proper fire suppression performance.

It is recommended that the current monitoring program be maintained or even enhanced to provide as much lead time as possible to initiate mitigation measures. Further enhancements to consider are:

- Including all maintenance personnel in mussel surveillance during their routine activities (some education will be necessary), and
- Collaborating with other groups locally and regionally to broadcast any reports of mussel sightings.

It is also recommended to monitor the progress of Zequanox, a new technology using biological control specific only to dreissenids currently in the process of commercialization by a California-based company, Marrone Bio Innovations. This product has the potential to replace chemical-based treatments.

1.0 Project Description, Background and Scope

1.1: Background

The January 2007 discovery of quagga mussels in Lake Mead and subsequent spread throughout the lower Colorado River system, along with the January 2008 discovery of zebra mussels in the San Justo Reservoir in San Benito County, California, have created significant concern among owners and operators of water supply systems throughout the West.

These non-native, invasive mussels are an environmental and economic nuisance, with the potential to harm ecosystems, affect water system reliability, damage equipment and infrastructure, and require significant investment to control. It is possible that zebra or quagga mussels (dreissenid mussels) will establish a presence in the Santa Clara Valley Water District's (SCVWD, District) imported source water. For the District, infestation of invasive freshwater mussels in source water could result in reduced flows through intake and piping systems, increased energy use to pump water through clogged lines, and taste and odor problems for delivered water if these negative impacts are not mitigated by installing appropriate control measures.

The District is already taking proactive measures to keep invasive mussels out of its reservoirs with boating inspections on four reservoirs and closure of boating on others (except by special permit such as the rowing club or ski club). The District has conducted mussel vulnerability assessments of three pumping plants, local reservoirs, and water treatment plants. The District has also implemented regular mussel monitoring and has developed an invasive mussel response plan.

Dreissenid mussels are aggressive bio-foulers. There are two main types of fouling: acute and chronic. It is essential that any facility experiencing mussel fouling be prepared to deal with both types of fouling.

Chronic fouling occurs when juvenile dreissenid mussels attach themselves to external and internal structures. The juvenile mussels grow in place and reduce water flow and, in some cases, can even cut off the water flow.

Acute fouling occurs when a large build up of adult mussel shells, alive or dead, becomes detached from upstream locations and is carried by the water flow into piping systems. The large quantities of mussel shells quickly plug small diameter pipes, fixed strainers, filters and heat exchangers. Such events can occur at unexpected times and, if not anticipated, can have rapid and significant consequences.

1.2: Overview of SCVWD System and Water Supplies

SCVWD provides watershed stewardship, wholesale water supply, and flood protection for Santa Clara County, California, in the southern San Francisco Bay Area. The District encompasses all of the county's 1,300 square miles (3,400 km^2) and serves the area's 15 cities and 1.7 million residents. The District's three water treatment plants can produce as much as 210,000,000 gallons (800,000 m^3) of drinking water a day.

Approximately half the water used in the county originates in the Sierra Nevada and is delivered through the Sacramento-San Joaquin River Delta or the Hetch Hetchy Aqueduct system. Most of the remainder comes from local rainfall, much of which is captured in the water district's 10 local reservoirs.

40% of Santa Clara County's water supply is conveyed through the Sacramento–San Joaquin River Delta. This water is supplied to the north side of the District via the South Bay Aqueduct (SBA), and to the south side of the District via San Luis Reservoir and the San Felipe System.

1.3: Scope of Work

Task 2 of the Invasive Mussel Control Measures for Imported Water Intake Project was performed to evaluate the District's imported source water system. The evaluation consisted of:

1. Analyzing environmental parameters and water quality data for the imported source water system to assist in estimating the size of the potential infestation and vulnerability of facilities,

2. Reviewing the existing SBA and Pacheco Pumping Plant vulnerability assessments,
3. Performing site assessments, and
4. Preparing this Technical Memorandum (TM) summarizing the findings.

Summarized in this TM are the findings on:

- Calcium-based assessment of environmental suitability for mussel establishment,
- Assessment of additional environmental parameters to determine if any may be limiting factors to the population size of the mussels,
- Descriptions of systems vulnerable to mussel fouling, and
- Preliminary discussions of possible practices for coping with invasion and control options for raw water systems.

This report focuses on identifying those structures and facilities which will be vulnerable to mussel-related impacts should an infestation occur in the future. This report contains what RNT Consulting, Inc. believes are practical options for dreissenid mussel mitigation at each facility, but it does not include an engineering evaluation of these options.

2.0 Assessment Process and Method

SCVWD provided the MWH/RNT team with various documents to prior to conducting site assessments. The following documents were provided to assist in completing our assessment:

1. SCVWD Memorandum, “Mussel Assessment for the Pacheco Pumping Plant,” dated July 28, 2009
2. “Santa Clara Valley Water District Vulnerability Assessments for Pumping and Treatment Plants,” July 2009
3. SCVWD Memorandum, “Disinfection at Pacheco Pump Plant for Mussel Control to San Luis Pipeline,” dated October 14, 2009
4. “Assessment of the Potential Impact of Quagga/Zebra Mussels on Selected Facilities and Structures of the California State Water Project; Recommendations for Monitoring and Control,” prepared by RNT Consulting, May 28, 2008.
5. Various flow diagrams, schematics, photographs and general arrangement drawings of raw water systems for the SBA Terminal Tank and Pacheco Pumping Plant as well as an outline of the overall system and the interconnections present.

Additional documents that were used to complete this TM are listed in Section 5.0: Literature Reviewed.

The MWH/RNT team, accompanied by staff from SCVWD, conducted site assessments on July 6, 2010. The site assessments included the SBA Terminal Tank at the Penitencia Water Treatment Plant (WTP), Piedmont Valve Yard, Bifurcation to Hollister Conduit, San Luis Reservoir, and the Pacheco Pumping Plant. Subsequent to the assessments, additional data on the water quality parameters was provided.

3.0 Results of the Assessment

3.1: Environmental Requirements for Mussel Infestation

Assessment of environmental suitability for mussel infestation is essential when assessing the vulnerability of facilities and structures. The environmental criteria used to estimate the possible level of infestation in temperate climates are provided in Table 1. Table 1 was derived from the values reported by various authors and gives the ranges of values for each of the parameters as they relate to success of dreissenid mussel populations.

Table 1. Criteria used in determining the levels of infestation in the temperate zone of the eastern portion of North America and Europe (Mackie and Claudi, 2009)

Parameter	No Sustained Infestation (no long-term survival by adults)	Low Infestation (Uncertainty of veliger survival)	Moderate Infestation	High Infestation
Calcium (mg/L)	<8 to <10	<15	16-24	≥24
Alkalinity (mg $CaCO_3$/L)	< 30	30-55	45-100	>90
Total Hardness (mg $CaCO_3$/L)	<30	30-55	45-100	≥90
pH	<7.0 or >9.5	7.1-7.5 or 9.0-9.5	7.5-8.0 or 8.8-9.0	8.2-8.8
Mean Summer Temperature (°F)	<64	64-68 or >83	68-72 or 77-83	72-75
Dissolved Oxygen mg/L (% saturation)	<3 (25%)	5-7 (25-50%)	7-8 (50-75%)	≥8 (>75%)
Conductivity (µS/cm)	<30	<30-60	60-110	≥100
Salinity (mg/L) (ppt)	>10	8-10 (<0.01)	5-10 (0.005-0.01)	<5 (<0.005)
Secchi depth (m)	<0.1or >8	0.1-0.2 or >2.5	0.2-0.4	0.4-2.5
Chlorophyll a (µ/L)	<2.5 or >25	2.0-2.5 or 20-25	8-20	2.5-8
Total phosphorous (µg/L)	<5 or >50	5-10 or 30-50	15-25	25-35

Calcium is considered the most essential environmental constituent when assessing the likelihood of long term mussel survival. Dreissenid mussels need calcium in order to build their shells. The larval forms (veligers) of dreissenid mussels require higher levels of calcium (in order to develop) than is required by adult mussels for survival. Therefore, adult mussels, if introduced into a body of water with low calcium, may survive for some time, but the population may fail to reproduce and therefore will be eliminated. Ideally, monthly calcium collected over several years should be used to assess how a dreissenid mussel population may develop in a given environment.

In the presence of adequate calcium levels, dreissenid mussels can proliferate unless another environmental parameter is limiting. pH influences shell development and maintenance due to the impact on calcium. A pH value in the range of 7.9 to 9.0 may enhance the population size of dreissenid mussels in areas where available calcium would be considered marginal.

3.1.1 Terminology for Densities

The assignment of the qualitative descriptors of low, moderate and high potential settlement of dreissenids is intended to indicate broad ranges of mussel density. Ramcharan et al (1992) consider low densities to be 1,000 to 3000 individuals per square meter (m^2) and high densities greater than approximately 4,800 individuals per m^2, but no rationale was given. More often, high density is considered one in which a square meter of surface is completely covered by at least one layer of mussels in one season. A typical adult mussel has a ventral surface area of approximately 2 cm^2. It would take 5,000 mussels to cover 10,000 cm^2 (i.e., 1 m^2), so annual settlement of greater than 5,000 individuals per m^2 is considered the criterion for high density and supports Ramcharan's et al (1992) estimate. Ramcharan et al (1992) considered 3,000 individuals per m^2 as the upper threshold of low densities because their data "appeared to represent a natural break in the density frequency distribution." However, 3,000 individuals per m^2 represents 60% coverage of a square meter of surface. A 30% coverage seems more appropriate, so we consider a low infestation level as one in which the annual settlement density is less than 1,500 individuals per m^2 and moderate infestation as annual settlement of between 1,500 and 5,000 individuals per m^2.

3.2: Suitability of the SCVWD System for Dreissenid Mussel Infestation

3.2.1: Calcium

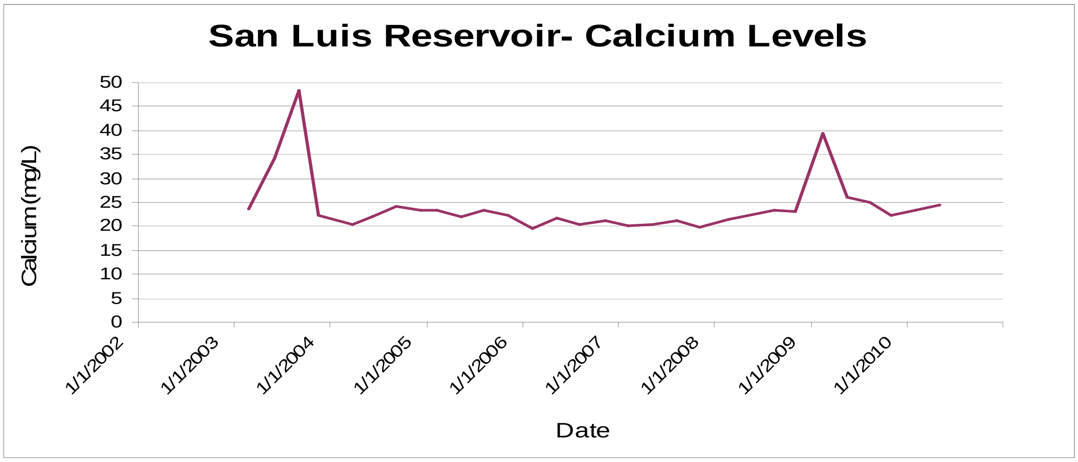
Calcium concentrations at San Luis Reservoir, Penitencia WTP, and Santa Teresa WTP are shown in Figure 1.

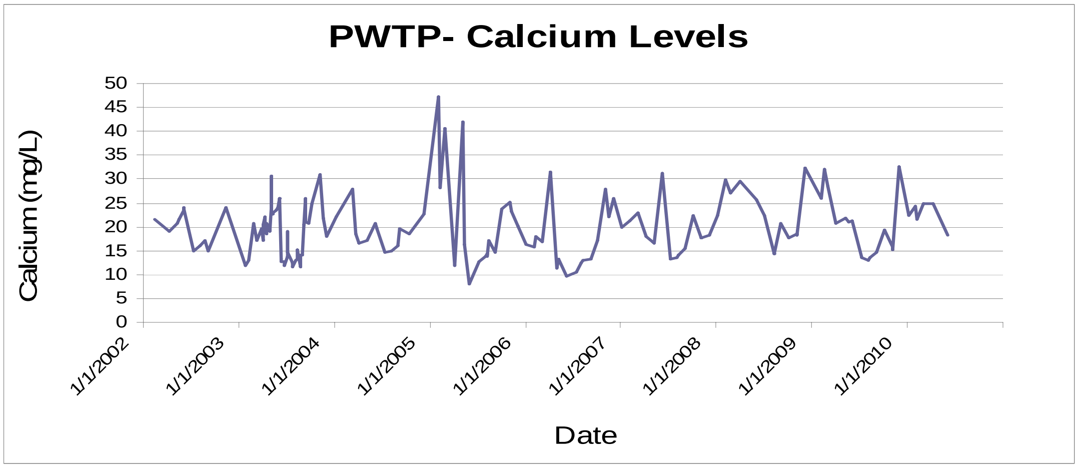
San Luis Reservoir has an average calcium concentration of 24.2 mg/L and appears to have more consistent calcium levels than the Santa Teresa and Penitencia water treatment plants. While calcium levels of around 40 mg/L have been recorded on at least two occasions in the San Luis Reservoir, the majority of the data available shows calcium levels between 20 and 25 mg/L. A calcium level of 25 mg/L is generally considered the minimum average calcium level required for successful establishment of dreissenid mussels. Using a conservative approach (due to the uncertainties of dreissenid survival in a new environment such as California), the average calcium levels in San Luis Reservoir would suggest that a moderate infestation may develop if dreissenids are introduced into the reservoir during the periods of higher calcium concentrations.

In comparison, the San Justo Reservoir has calcium levels in the 24 to 26 mg/L range (J. Janik, personal communication) and a thriving population of zebra mussels. The success of this population may be driven by the relatively high pH levels in the epilimnion of the reservoir (7.9 to 8.3).

The average calcium concentration at the Santa Teresa WTP is 24.8 mg/L which is comparable to the San Luis Reservoir. The Santa Teresa WTP periodically receives water from the Anderson Reservoir which has been shown to have mean calcium levels of 41.2 mg/L (Cohen 2009).

Penitencia WTP has an average calcium concentration of 19.8 mg/L. Using a conservative approach, this would indicate that a low to moderate infestation may develop in the District’s segment of the SBA if dreissenids are introduced into the SBA source water.





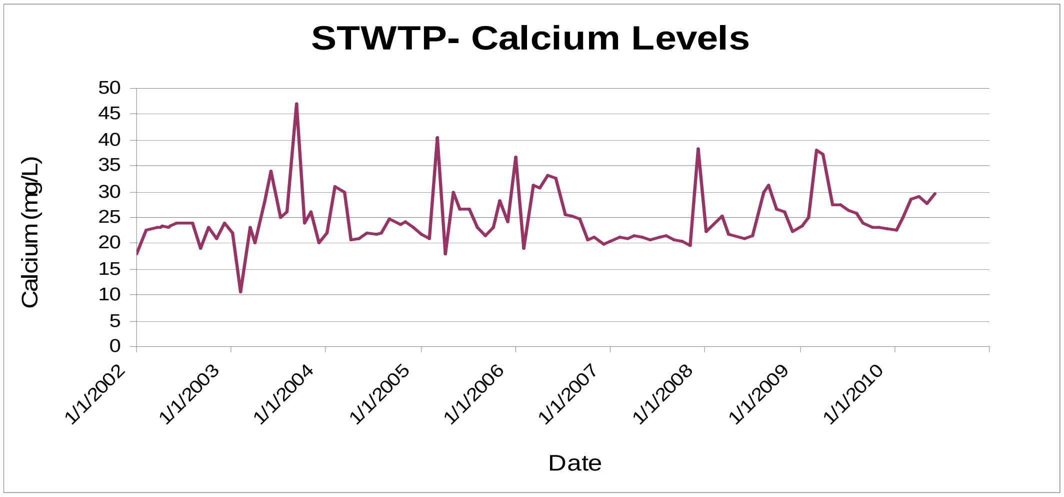


Figure 1. Calcium levels in San Luis Reservoir, Penitencia WTP and Santa Teresa WTP

3.2.2: Other environmental variables

Calcium is considered the most essential environmental constituent when assessing the likelihood of long term mussel survival. In the presence of adequate calcium, other environmental parameters are evaluated as possible moderating factors. With the exception of pH, the additional environmental parameters may only decrease the possibility and size of dreissenid infestation. High pH, however, may increase the population size in lakes with relatively low calcium levels.

3.2.2.1 pH

Figure 2 shows changes in pH with time for San Luis Reservoir, Santa Teresa WTP, and Penitencia WTP. The analysis of the available pH values indicates that pH would not be an additional moderating factor for dreissenid populations and it may actually enhance them.

The pH in San Luis Reservoir has an average of 7.6 but appears to fluctuate considerably between 7.0 and 8.7, most likely due to algal activity. These pH values (coupled with the reported calcium concentrations) indicate that there is potential for the San Luis Reservoir mussel population to be in the moderate-to-high range.

The average pH at Santa Teresa WTP is 7.8, slightly higher than San Luis Reservoir. The pH at Santa Teresa WTP seems to oscillate somewhat regularly between 7.5 and 8.5 with some outliers. In all years plotted, the pH peaked in late summer or early autumn.

Penitencia WTP has an average pH of 8.0 with most values falling between 7.7 and 8.3. The pH often exceeds 8.5 at Penitencia WTP, and it occasionally drops below 7.5. These pH values (coupled with the reported calcium concentrations) indicate that there is potential for the SBA mussel population to be in the moderate range.

To better predict the potential level of dreissenid infestation in the SBA and San Luis Reservoir, weekly samples should be collected and analyzed for calcium and pH for one year to develop seasonal profiles. Calcium and pH samples should be collected with some regularity in subsequent years to catch any long-term changes that may be occurring.

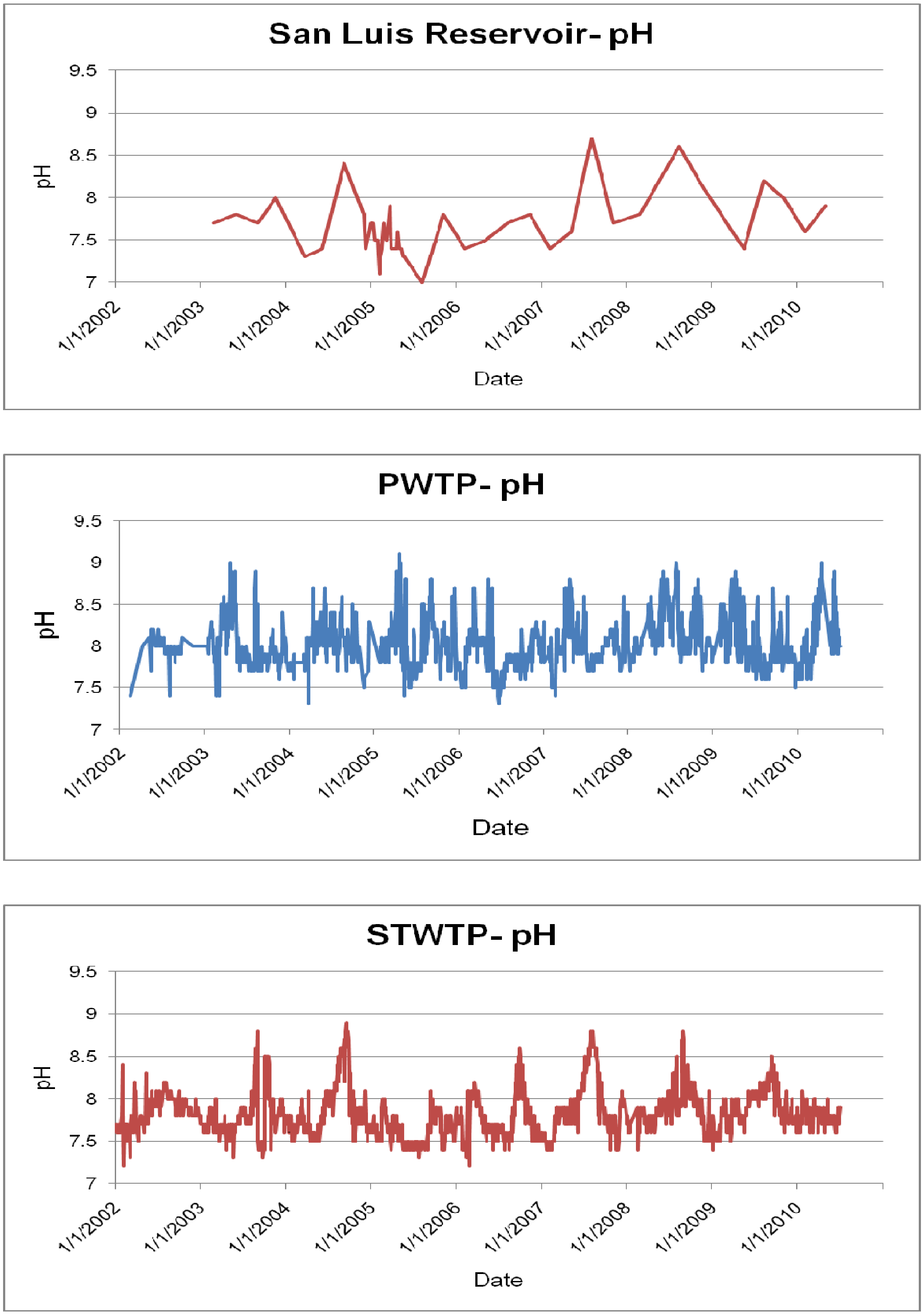


Figure 2. pH levels in San Luis Reservoir, Penitencia WTP and Santa Teresa WTP

3.2.2.2: Temperature

Mean summer temperatures must be between 22°C and 24°C (72°F and 75°F) to support a high infestation of dreissenid mussels and between 20°C and 28°C (68°F and 83°F) to support a moderate infestation. Figure 3 shows water temperatures for San Luis Reservoir, Santa Teresa WTP and Penitencia WTP. In general, the reservoir temperatures range from around 12°C to 22°C (54°F to 72°F) throughout the year, with a summer average of 19.4°C (66.9°F). Santa Teresa WTP water temperatures are very similar to the reservoir, ranging from approximately 12°C (54°F) to 24°C (75°F). The average summer temperature of Santa Teresa WTP water is 19.6°C (67.2°F). Penitencia WTP has a larger range in water temperatures over a year, showing winter temperatures around 10°C (50°F) or lower and reaching summer highs greater than 25°C (77°F). The average summer temperature of Penitencia WTP is 22.5°C (72.6°F).

Average summer temperatures suggest that water temperature may be limiting to dreissenid mussel growth in both San Luis Reservoir and Santa Teresa WTP. During the period from July to September, though, both the reservoir and the WTP typically have water temperatures of 20°C to 22°C (68°F-72°F). At these temperatures, a moderate dreissenid mussel infestation could be supported. Penitencia WTP generally has water temperatures above 20°C from late May until October and could therefore support a moderate dreissenid mussel population.

In summary, temperature would not be likely to further moderate the levels of infestation dictated by the calcium availability.

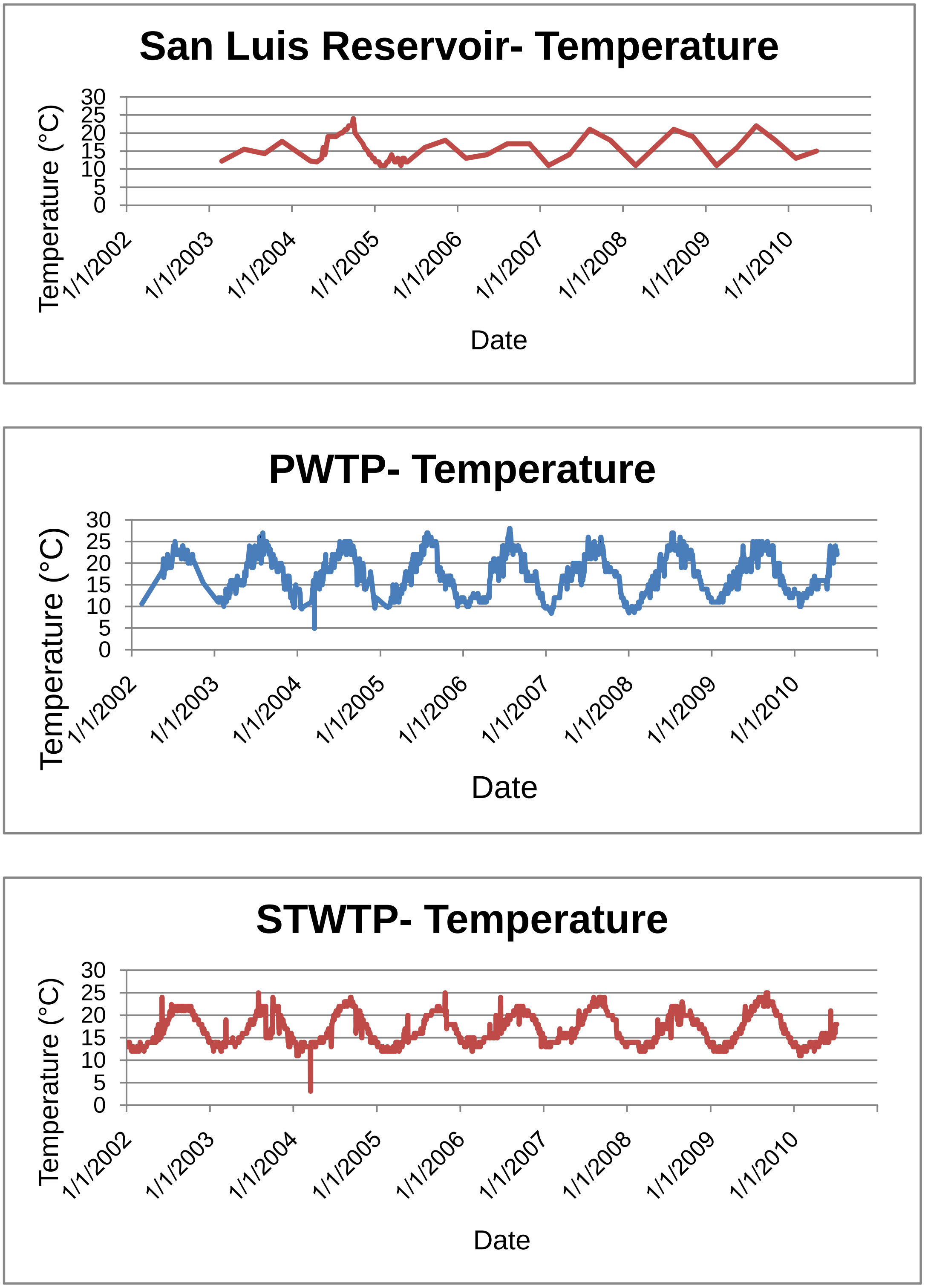


Figure 3. Temperature plots for San Luis Reservoir, Penitencia WTP and Santa Teresa WTP

3.2.2.3: Dissolved Oxygen

The dissolved oxygen (DO) concentrations in San Luis Reservoir appear to fluctuate widely (Figure 4). Nevertheless, dissolved oxygen is not likely to be a limiting factor to dreissenid population in San Luis Reservoir. The average DO concentration is 8.1 mg/L, but values have dropped as low as 5.2 mg/L in the last 9 years, and they occasionally exceed 10 mg/L. Dissolved oxygen data were not available for Santa Teresa WTP and data for only the end of January to the beginning of April 2005 were available for Penitencia WTP. The Penitencia WTP data show an average dissolved oxygen concentration of 10 mg/L and the data range from 7.6 mg/L to 11.6 mg/L.

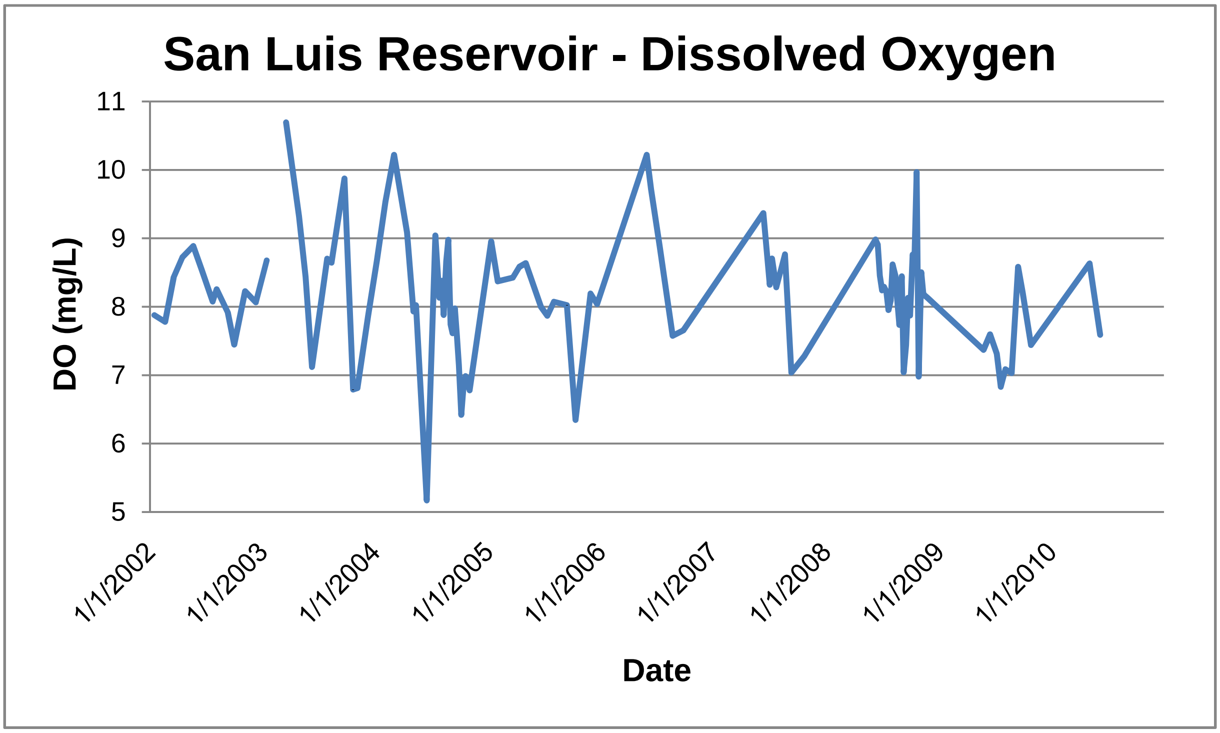


Figure 4. Dissolved oxygen concentrations in San Luis Reservoir

Based on the above data, oxygen is not likely to further moderate the levels of infestation dictated the calcium levels

3.3: Review of the Facilities

3.3.1: Penitencia Water Treatment Plant

The Penitencia WTP receives water from the SBA, via the SBA Terminal Tank located on the treatment plant property.

The water entering Penitencia is pre-chlorinated directly at the treatment plant. The primary disinfection of the incoming water at the WTP is via ozone. Chloramines are added prior to delivery of the water to the transmission system to provide a residual for distribution.

The incoming water pH is adjusted at the plant. The pH of the incoming water can vary widely, from approximately 7.0 to 9.1. Outgoing water from the plant is typically adjusted to a pH of 7.6.

Reducing the pH of the water to 7.2 is one means to eliminate all life stages of the mussels. However, lowering the pH of the raw water would not be acceptable because the piping is mortar lined and continuous low pH would eventually weaken the mortar lining of the pipe walls.

Raising the pH is also an effective means of control mussel life stages and may be acceptable to operating staff. The cost of raising raw water pH and any post-WTP reduction of the pH to levels acceptable to the water customers should be evaluated. If the approach is economically acceptable, a field test to verify that SBA water with a pH of 9.3 would prevent mussel settlement should be conducted.

Copper sulfate is reportedly added to the open channel area of the SBA. The reason for the copper sulfate addition is primarily algae control. Treatments are approximately every two weeks, depending on the algae levels.

Copper sulfate is known to kill mussels, and a means to control mussels may already be in place if the current concentration and frequency used in the imported SBA water is sufficient to control mussels. There are obvious permitting and cost benefits to extending an existing treatment method to control mussels.

The frequency, concentration, and purpose for copper sulfate addition needs to be confirmed. If the use of copper sulfate appears practical for mussel control, then the concentration of copper sulfate required to eliminate freshly-settled mussels (two to three weeks old) in the SCVWD source water needs to be confirmed.

The SBA Terminal Tank receives and holds raw source water for the Penitencia WTP. The tank is 160 feet in diameter and 20 feet tall. The inlet is a 6-foot diameter pipe which terminates in a vertical riser with a diameter of 11 feet. The riser extends vertically above the top of the tank and incoming water spills over the lip of the riser into the tank. The outlet consists of an 11-foot diameter overflow riser feeding a 42-inch diameter outlet pipe. The tank would likely function as an effective settling pond for dead mussel shells that are transported via velocity of the source water. This would keep dead shell material from entering the Penitencia WTP proper. The tank walls will provide a settlement substrate for mussel larvae. Other than being an operational nuisance to clean the mussels from the tank walls, the mussels would not likely cause any problems for the WTP during normal treatment operations. Eggs and larvae that are released from spawning mussels in the tank will be killed by the water treatment process. Parts of the plant that are not operating (or operating as normal) may be subject to increased risk if other control measures are not in place upstream. Specific areas that fall under this category should be assessed separately.

Currently, settlement plates are installed in the tank to monitor for mussel arrival. The plates are checked monthly.

The reservoir surplus of the tank is directed to percolating ponds. Spilled or drained water from the reservoir or ponds may enter a local creek. Therefore, chemicals in spilled water are an issue that needs to be considered as part of any overall mussel control program. Live mussel veligers that are spilled into the local creek may be transported to other water bodies depending on the route and water flow of the creek.

3.3.2: Piedmont Valve Yard

The Piedmont Valve Yard has two vault chambers, each with an isolation valve. Also in the yard are accesses for blow off valves plus a voltage transformer. Maintenance access for large component removal/replacement in the valve vaults is via removable vault roof structures that require a small crane.

Large pipeline valves that operate periodically are unlikely to experience mussel problems. Mussels attached in the area of the seats of normally open valves may result in shells trapped in the valve seats when the valve closes. This may permit leakage past the seats. Cycling of the valve usually flushes the mussels from the seats. Large valves that are normally closed typically have operators that would be able to open a valve even with significant mussel accumulation.

Air release valves within the vault or elsewhere in the piping system are smaller than line valves and more vulnerable to mussels. Typical problems would be leakage past the valve seat if a shell is propelled into the seat area during an air release or impaired operation of the float assembly from mussels accumulating on the float.

Should it become necessary to drain a line, all air vents should be checked for proper operation in the event mussels have managed to settle in the wetted portions of the vent line. Should it be impractical to check air vents either prior to or during a draining operation, the pipe wall collapse pressure should be determined or checked. If pipe wall collapse is a possible outcome of plugged vent lines, the drain process should not proceed without first inspecting the vent lines.

The yard is located in a residential area, but periodic use of large maintenance equipment is not a problem for the residents. There should be easy access to the vaults for any additional maintenance required due to mussels.

There is an emergency power supply in the yard with an internal combustion engine. The engine is air cooled and does not use raw water. Mussels will not affect the operation of the generator.

Flow meters are understood to be ultrasonic design. In this design there is no contact with raw water. The performance of the non-contact flow meters will not be affected by mussels.

3.3.3: Bifurcation to Hollister Conduit

At the bifurcation yard, the flow from the Pacheco Conduit is divided and directed into the Hollister Conduit and the Santa Clara Conduit. The Hollister isolation valve is normally open, which is of concern to the SCVWD because the presence of mussels has been confirmed in San Justo Reservoir.

Under the current operating regime, back flow from San Justo Reservoir into the Santa Clara Conduit is prevented by keeping pressure at the vault higher than pressure from San Justo Reservoir. The Hollister isolation valve is controlled by others, but SCVWD has the right to over ride and shut the isolation valve in the event that SCVWD judges an emergency condition exists. Backflow from San Justo Reservoir with mussel-laden water would be considered an emergency operating condition.

There are no other valves in the Hollister line that could serve as an isolation valve. If San Justo Reservoir water is not required by SCVWD, then a check valve could be added to serve as an additional passive barrier to reverse flow. A double chambered back flow prevention valve would provide even greater passive protection.

There are two flow meters in the bifurcation vault. They are ultrasonic design and have no contact with raw water.

A biobox has been installed in the bifurcation vault on the Hollister Conduit (the San Justo side of the bifurcation valve) to monitor for mussel arrival.

3.3.4: Pacheco Pumping Plant and San Luis Reservoir

3.3.4.1: General Overview

The Pacheco Pump Plant withdraws water from San Luis Reservoir. The plant takes in water through an intake and tunnel system into a suction vault. Twelve identical vertical-shaft multistage pumps deliver water to a common discharge manifold. The discharge manifold delivers water to a regulating tank for subsequent delivery via gravity into the Pacheco Conduit.

3.3.4.2: Pump Plant Intake Structures

There are two intakes, upper and lower, each covered with intake grates. The intake grates are not removable. The grate is a grid configuration which is shown to colonize more easily and more rapidly than the more common vertical bar configuration. The grate structure will be at significant risk from mussels, should they become established in San Luis Reservoir. The grate openings can be partially blocked by mussel accumulation and cause a restriction in the maximum flow available. The upper intake is normally still below the water surface at low water level. Therefore, inspection and cleaning of both intakes will need to be done by divers. The most convenient time to deploy divers would likely be at the low point in the reservoir cycle. Consideration should be given to replacement of the grates with a design that is less susceptible to settlement (by using coatings) or blockage (by using vertical bars-only), and is easier to clean (e.g., extra sets of grates that can be replaced to allow cleaning on land).

Coatings can assist in reducing the impact of mussels on grates, screens and trash racks where blockage would be a problem and on areas where sloughing of large shell clumps would be a problem, such as pump wells. The intake grates at San Luis Reservoir are a possible point application of this technology. The most successful coatings appear to be silicon-based foul release coatings. Their weakness during testing by the U.S. Bureau of Reclamation appears to be from mechanical damage to the coating by floating or submerged objects.

SCVWD may consider, as one of its mussel control options, to treat all the source water withdrawn from San Luis Reservoir. The most likely treatment method in this option would be chemical injection. Delivering chemicals to the intake tunnel extremities will be difficult. Typically this is done via chemical delivery pipes inside the intake tunnel that terminate at a chemical diffuser at or near the intake grates. Chemical lines can be installed retroactively using a bladder and small tow line subsequently used to install a larger tow line. Multiple chemical delivery lines are usually installed for redundancy. The lines are attached to a diffuser that is positioned at the extremity of the intake tunnel as near as practical to the intake grates.

The pumping plant surge tower is another possible location for general chemical addition if this is the chosen response to mussels. The chemicals could be delivered to the pump forebay vault, protecting all areas except the intake tunnel and intake grates.

Delivery of chemicals to the intake tunnel may not be necessary, because moderate to high infestation levels may be tolerable in the intake tunnel as it has a relatively large diameter (9.5 feet). The intake grates could be cleaned (or swapped out) manually by divers and the intake tunnel left to accumulate mussels. The mussels in the intake tunnel would be a source of shells that would eventually be transported to the pump forebay vault. Mussels would accumulate in the tunnel, layer upon layer, and eventually (after approximately 3 years) the initial layer will begin to die off. An operational procedure would be to let mussels attach, grow, die and slough off. It will be necessary to evaluate if shell accumulation can be tolerated in the pump forebay vault. Shell accumulations in the pump forebay vault could be vacuumed from the surge tower or allowed to pass through pumps if additional wear is tolerable on pump bearings, shaft seal sleeve and impeller rings and downstream transport of shells is acceptable. The regulating tank may serve as a settling pond for any shells limiting the transport of shell material in the Pacheco Conduit.

3.3.4.3: Domestic Water

There is no domestic water system in the plant. Drinking water is bottled water.

3.3.4.4: Station Service Water

Service water is raw water taken off the discharge manifold at a single location. Service water is used for air chillers, fire water, and general service taps. Except for the fire water, a duplex strainer is provided and will remove dead mussel shells except for shell fragments smaller than the screen mesh size. However settling-sized mussel veligers will pass through the strainer, and downstream components will be at risk of mussel settlement. Settlement in piping should be minimal as almost all service water piping is copper.

Hydraulic oil and air compressors do not use raw water.

3.3.4.5: Fire Protection Water

The fire water system is at risk of both mussel shell debris and, to a lesser degree, mussel settlement. There were no fire sprinklers in the fire control system, only hoses with fire water nozzles. The fire water piping is made almost completely from copper material. There should not be mussel settlement on the piping unless a biofilm accumulates on the piping. Mussels can then attach to the bio-film. Mussels on the biofilm are generally easy to remove; however, the removed mussels become a source of shells which may impair the performance of the fire hose nozzles.

Fire protection systems are often assumed to be naturally resistant to mussel settlement due to long periods of no use resulting in stagnant water. However, garden hoses were observed to be connected to bibs on the fire protection system at Pacheco Pumping Plant. It is expected that the hoses are used for general cleaning purposes and not for fires. The use of the garden hoses will draw fresh water into the piping, bringing food and oxygen to any mussels which might settle within the fire protection piping and components. This practice should be discontinued and the system should be kept as static as possible in between regular test cycles.

If the fire protection piping can be kept stagnant and time between fire protection system testing is long, veligers should not be able to survive as the water will become low in dissolved oxygen during the periods between system uses or testing. The rate of decay of oxygen should drop below the survival threshold (3 mg/L) within three weeks. However, should mussels begin to settle in the plant, the rate of oxygen decay should be measured as the decay can be variable depending on the particular water conditions.

3.3.4.6: Unit Cooling Water

Pump unit cooling water is taken off each pump discharge. Raw water provides cooling water for the motor air cooler, motor thrust and guide bearings and pump stuffing box. A duplex strainer is provided and will remove dead mussel shells. The strainer basket pore size is unknown. The strainer could prevent ingress of shells but not primary settlement. The pore size of the strainer basket may let small mussel shell fragments enter the pump shaft stuffing box which will result in increased wear on the shaft sleeve.

Small adult translocators and settling-age veligers will pass through the strainers and can colonize the piping. Typically, in piping this size with high flow rates, heavy colonization does not occur, or if it occurs, the build-up is slow. Light colonization may be tolerable to the equipment performance but after a period of time mussels in the piping will begin to die, and the shells shed from the pipe walls can plug the heat exchanger tubes.

The most common area for mussels to accumulate is in the tube inlet and outlet manifolds of the air-to-water heat exchangers and in the shell cavity of oil coolers. These areas tend to have lower flow velocities and are more attractive settlement areas for live mussels.

The manifolds and shell side cavities are also catchment areas for any shells or shell fragments that manage to find their way along the upstream piping. Shell material can gradually accumulate in these areas, ultimately blocking tubes and causing poor performance of the coolers. If poor cooler performance is detected by equipment health monitoring, the maintenance personnel should be advised that mussel shell accumulation is a possible cause so they can take appropriate investigation steps.

If cooling water temperatures rise above 29.5^{o}C (85°F) on the discharge side of heat exchangers, then mussels will not settle in the downstream piping. Any mussels that have settled when the cooling water discharge temperature is below 85°F will die if the temperature rises above the mussel tolerance threshold (85°F) for a period of several consecutive hours.

Cooler tubes are typically manufactured of high copper content material and have high flow velocities. Mussels do not usually settle in these areas. However, tube diameters may be small enough to be blocked by dead mussel shells or clumps of shells that have detached from upstream locations.

To protect pump components from shell debris, a filter on each pump will be necessary. Alternatively, the pumping plant layout with all pumps oriented in a symmetrical line, lends itself to installing a common header system (collection and delivery headers) with a single filter large enough to filter pump unit cooling water for all pumps.

The pump cooling components (motor air cooler, motor thrust and guide bearings and pump stuffing box) will need a means to prevent mussel settlement in the components. The piping portions will likely not have mussel settlement problems as the piping is copper material which is resistant to mussel settlement. For the other pump cooling components, typically chemical addition, UV, or small-pore filters are used to prevent mussel settlement.

Pump impeller bearings are self lubricated with raw water. They are not at risk of settlement but pump impellers, wear rings, and bearings could experience increased wear if the pumped water has small shell fragments. The fragments are hard and abrasive. The bearings are journal bearings with a chromed shaft sleeve and proprietary metal journal material. Premature or accelerated wear of the bearing material will be costly to repair as the entire pump shaft must be withdrawn from the pump well.

3.3.4.7: Outside the Plant

There is an emergency power supply with an internal combustion engine in a small structure outside the plant. The engine is air cooled and does not use raw water.

The transformer enclosure does not use any raw water. Fire protection is via hose cabinets mounted on the exterior walls of the plant building and connected to the main fire protection system.

3.3.4.8: Regulating Tank

The discharge from the pumping plant enters the 3,700,000-gallon Pacheco regulating tank. This tank will likely be a good settling point for dead shells that are transported along the piping by the velocity of the water flow. Settling of dead shells within the tank will prevent dead shells from entering the piping delivery system. The details of the regulating tank interior should be checked to confirm that the water flow will allow mussel shells to settle within the tank. Dead shell material would need to be vacuumed periodically. The tank has an open top which permits access for cleaning online or offline.

Unless prevented through chemical addition or other means, live mussel veligers could flow past the tank and into the piping system, subsequently settling along the pipe or other downstream components.

3.3.4.9: Instruments

Although not specifically evaluated, it is likely that there are instruments used to track the water levels, pressure, and flow at various locations throughout the SCVWD system. Instruments that rely on contact with raw water are an often overlooked source of maintenance effort stemming from mussel infestations.

Should cleaning of the equipment become an onerous task, the use of non-contact instrumentation such as ultra-sonic or infra-red level probes can be considered.

3.4: Inspecting for Mussel Accumulation

SCVWD has a number of locations which can be periodically inspected as part of the normal maintenance cycle and could be inspected for mussel accumulations at that time. RNT suggests that maintenance staff be educated on what dreissenid mussels look like and whom to call when suspicious material is found.

3.5: Monitoring

SCVWD has a proactive monitoring program for early detection. Plate samplers have been set up at several locations and these plates are inspected on regular basis for mussel settlement. Bio-boxes have been installed in critical locations to further assist with settlement detection. In addition to settlement samples, SCVWD also takes plankton samples to look for free swimming dreissenid veligers. In addition to the monitoring effort already in place, we would suggest involving maintenance staff in checking for dreissenid mussels during their normal maintenance duties. This may involve a workshop for maintenance personnel to demonstrate what they may be looking for and to give them a contact person to report any findings. Posting contact information at all facilities would be helpful.

4.0: Findings and Recommendations

4.1: Findings

Based on RNT's review of the SCVWD facilities visited, the following findings are offered:

- Imported source water facilities which receive water from the SBA and San Luis Reservoir have potential vulnerability to negative impacts from dreissenid mussels.
- Calcium, pH, temperature, and dissolved oxygen data for the SBA suggest the possibility of moderate infestations of dreissenid mussels in the future.
- Calcium, pH, temperature, and dissolved oxygen data for San Luis Reservoir suggest the possibility of moderate-to-high infestations of dreissenid mussels in the future.
- Raising the pH of SBA water may be an effective means of control mussel life stages and protecting facilities that receive SBA water. Copper sulfate is currently added to SBA water and may serve as a means to control mussels.
- If treatment of water taken from San Luis Reservoir is desired, suitable chemical injection locations are available in the intake tunnel (just inside the intake screens) or at the intake surge tower. Neither option will prevent accumulation of mussels on the intake grates, which will require manual cleaning.
- Should mussel accumulation be tolerable to the SCVWD system piping, increased maintenance will be required to clean dead shell material from areas of low flow. The Pacheco Pumping Plant forebay vault, regulating tank, and the SBA Terminal Tank will likely be locations of high shell debris accumulation.
- Protection strategies for Pacheco Pumping Plant include 1) periodic treatment for maintenance purposes, and 2) continuous treatment to prevent passage of veligers downstream of Pacheco Pumping Plant.

- If periodic treatment for maintenance purposes is selected, it is possible that a once per year treatment could be practical, given the projected levels of infestation based on environmental data. This practice would allow one year of mussel growth within the system between treatments to remove growth.

4.2: Recommendations

Based on RNT's review of the SCVWD facilities visited, the following recommendations are offered:

- Weekly samples (for calcium and pH) for one year should be collected from each imported source water to develop seasonal profiles to better predict the potential level of dreissenid infestation.
- The cost of raising SBA raw water pH and reducing treated water pH should be evaluated. If the approach is financially and technically acceptable to the District, a field test to verify that SBA water with a pH of 9.3 would prevent mussel settlement should be conducted.
- The frequency, concentration, and purpose for copper sulfate addition at the open channel area of the SBA canal needs to be confirmed. If the use of copper sulfate appears practical for mussel control, then the concentration of copper sulfate required to eliminate freshly-settled mussels (two to three weeks old) in the SCVWD source water should be determined through testing.
- Protection strategies for Pacheco Pumping Plant (listed above in Section 4.1: Findings) should be considered and prioritized. The feasibility of control methods can be evaluated once a protection strategy is defined.
- Protection options for the pump cooling water system at Pacheco Pumping Plant should be evaluated. Small-pore filters, UV irradiation, or chemical injection are all suitable methods. UV will kill veligers but may require filters to keep out shell fragments.
- Some improvements or modifications to the Pacheco Pumping Plant fire suppression system are needed to ensure that a flush of shell material does not occur during a fire use, thereby impairing fire nozzle performance.

- Obtaining permits from the appropriate regulatory agencies should be initiated in order to begin mitigation when required. Discussions with the regulatory agencies should include Zequanox, pH adjustment, oxidizing chemicals, and possibly copper sulfate.
- The progress of the Zequanox product should be monitored, as this product has the potential to replace oxidizing chemicals for mussel control.
- Action plans for each system that requires protection should be initiated. The District should continue to monitor for mussel arrival and be prepared to implement the action plan at critical locations (e.g., the Pacheco Pumping Plant) once mussel arrival is confirmed.

5.0: Literature Reviewed

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